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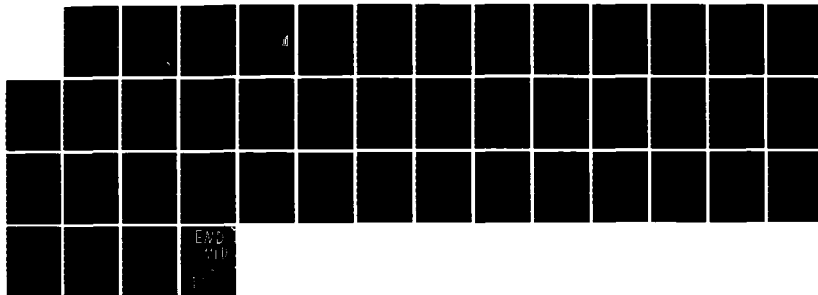
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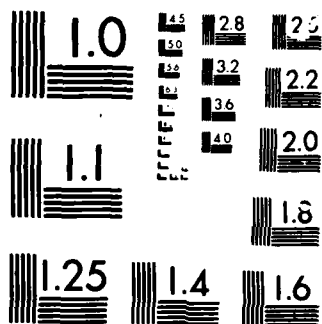
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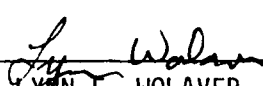
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ABSTRACT

A Study of NO Gamma Bands in the Mesosphere

From Spacelab 1

by

Edward H. Erwin, Master of Science

Utah State University, 1985

Major Professor: Dr. Marsha R. Torr

Department: Soil Science and Biometeorology

→ The Imaging Spectrometric Observatory obtained simultaneous spatial, as well as spectral data of NO in the mesosphere during the 1983 Spacelab 1 mission. The well defined rotational lines of the 1-0 gamma band in the ultraviolet were used to infer atmospheric temperature profiles. The slant path intensity profiles exhibit higher intensities than are predicted by a recent model and are in good agreement with the NO profile obtained in the infrared during the same Spacelab 1 mission. (Times)

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A STUDY OF NO GAMMA BANDS IN THE MESOSPHERE

FROM SPACELAB 1

by

Edward H. Erwin

A report submitted in partial fulfillment  
of the requirements for the degree

of

MASTER OF SCIENCE

in

Soil Science and Biometeorology

with emphasis in

Aeronomy

Approved:

Mark A. Tor  
Major Professor

Gene L. Holdridge  
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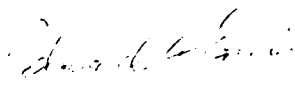
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I am very grateful to the United States Air Force for providing me with the opportunity to pursue my advanced degree at Utah State University.

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Edward H. Erwin

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ABSTRACT

A Study of NO Gamma Bands in the Mesosphere

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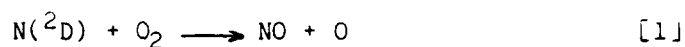
Department: Soil Science and Biometeorology

The Imaging Spectrometric Observatory obtained simultaneous spatial, as well as spectral data of NO in the mesosphere during the 1983 Spacelab 1 mission. The well defined rotational lines of the 1-0 gamma band in the ultraviolet were used to infer atmospheric temperature profiles. The slant path intensity profiles exhibit higher intensities than are predicted by a recent model and are in good agreement with the NO profile obtained in the infrared during the same Spacelab 1 mission.

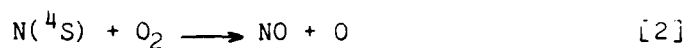
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## INTRODUCTION

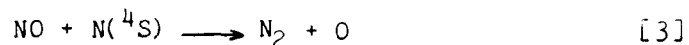
Nitric oxide is one of the main odd nitrogen forms in the upper atmosphere, along with ground state atomic nitrogen,  $N(^4S)$ , and its first excited state,  $N(^2D)$ . The production of nitric oxide is mainly from reactions involving atomic nitrogen and molecular oxygen (Norton and Barth, 1970):



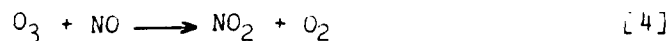
and



Nitric oxide and atomic nitrogen are sinks for each other through the reaction:



Nitric oxide is also an important sink for the destruction of ozone through the reaction (Crutzen, 1979):



The photodissociation of NO by Lyman-Alpha radiation and the charge conversion of  $O_2^+$  to  $NO^+$ , ensure  $NO^+$  is the major ion in the D-region of the ionosphere.

Since odd nitrogen plays an important part in the chemistry of the upper atmosphere, measurements of nitric oxide concentrations are highly significant in the testing of any chemical model (McCoy, 1983).

The temperature of the atmosphere and its variation with altitude (see Figure 1) are major factors in determining the properties of the atmosphere. The maxima in the temperature profile are produced by selective absorption of energy by the atmosphere at different wavelengths and altitudes. The nodes in the lower 100 km of the atmosphere roughly divide the atmosphere into different layers or spheres, each having its own atmospheric properties. Incoming solar radiation (insolation) with wavelengths  $<3000 \text{ \AA}$  do not reach the earth's surface. Insolation in the wavelength range of  $2000\text{--}3000 \text{ \AA}$  penetrates through the mesosphere into the upper portion of the stratosphere before being absorbed by atmosphere constituents (see Figure 1). Because of this atmosphere absorption, the best platform to obtain spectrometric observations of NO is from space.

Measurements of the NO gamma bands in the earth's upper atmosphere were first obtained in 1964 by rocket (Barth, 1964). Since that time, vertical profiles of the 1-0 gamma band fluorescence have been inferred from rocket and satellite measurements (Barth, 1964, 1966a, 1966b; Pearce, 1969; Meira, 1971; Rusch, 1973; McCoy, 1983; Frederick and Serafino, 1985).

#### Objective

The objective of this paper is to report on the NO 1-0 gamma band intensities in the ultraviolet obtained from Spacelab 1. These results will be compared to the latest theoretical global model of NO concentrations (Gérard et al., 1984) and to measurements of NO in the infrared obtained on the same Spacelab 1 mission (Laurent et al., 1984). Atmospheric temperatures will be inferred by the rotational lines of the 1-0 gamma band.

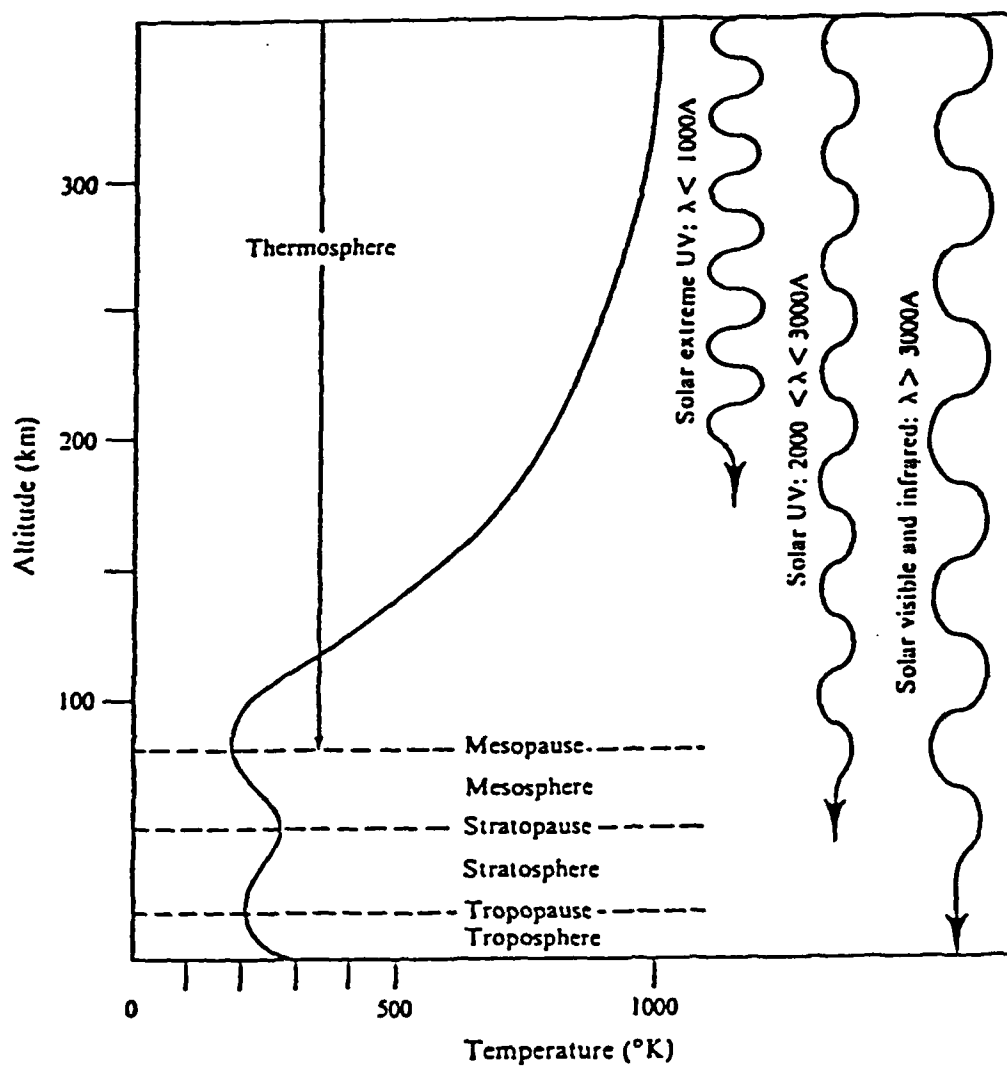


Figure 1. Temperature variations with altitude at middle latitudes. High temperatures are due to absorption of solar radiation, as shown at right (Goody and Walker, 1972).

## DATA ACQUISITION

Measurements of the NO gamma bands were taken from Spacelab 1, flown on the space shuttle during its 10-day (28 November-7 December, 1983) mission by the Imaging Spectrometric Observatory (ISO). The ISO is an array of 5 spectrometers, each covering a portion of the wavelength range 300-12700 Å, with 3-6 Å resolution. Each spectrometer works in parallel, obtaining its spectra in 20 steps of approximately 200 Å each. The ISO has been described in detail elsewhere (Torr et al., 1982).

On the last day of the mission, the shuttle was oriented to allow continuous limb scanning from its altitude of 250 km to a tangent ray height between 95-115 km (see Figure 2). Each spectral cycle was obtained over a 10-minute period, with the shuttle's ground track for the 8 continuous cycles shown in Figure 3. A summary of relevant parameters can be found in Table 1. Due to system problems, no data was available for cycle 3.

The ISO is also capable of simultaneous spatial as well as spectral imaging depending on the orientation of the entrance slit. With a field of view of  $0.65^\circ \times 0.007^\circ$  and the slit oriented with the long dimension perpendicular to the limb, a vertical atmospheric segment of approximately 16 km can be viewed with 2 km resolution. The ability of the ISO to produce spatial as well as spectral imaging makes it unique in its own right. The data received by the ground station was in a compressed mode, i.e., the eight spatial lines (2 km resolution) comprising the 16 km height profile were summed into a

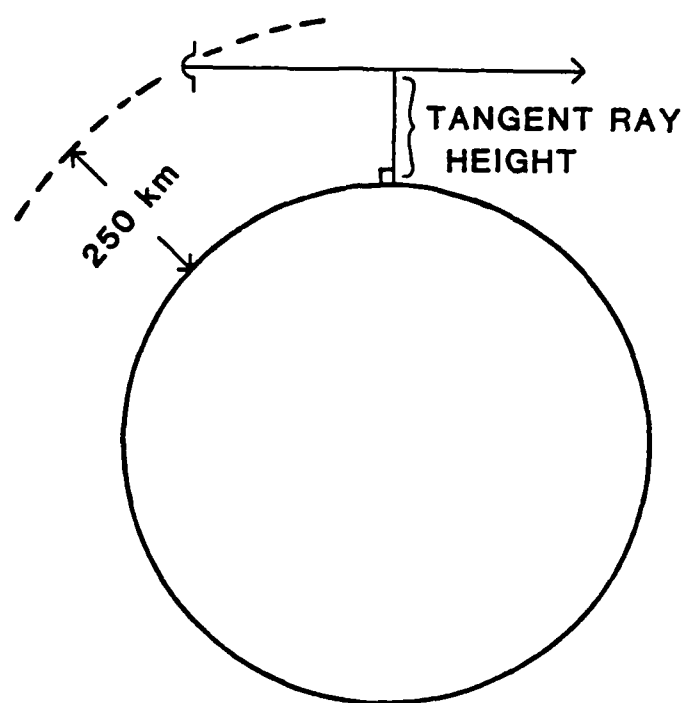


Figure 2. Space shuttle orientation during data acquisition.

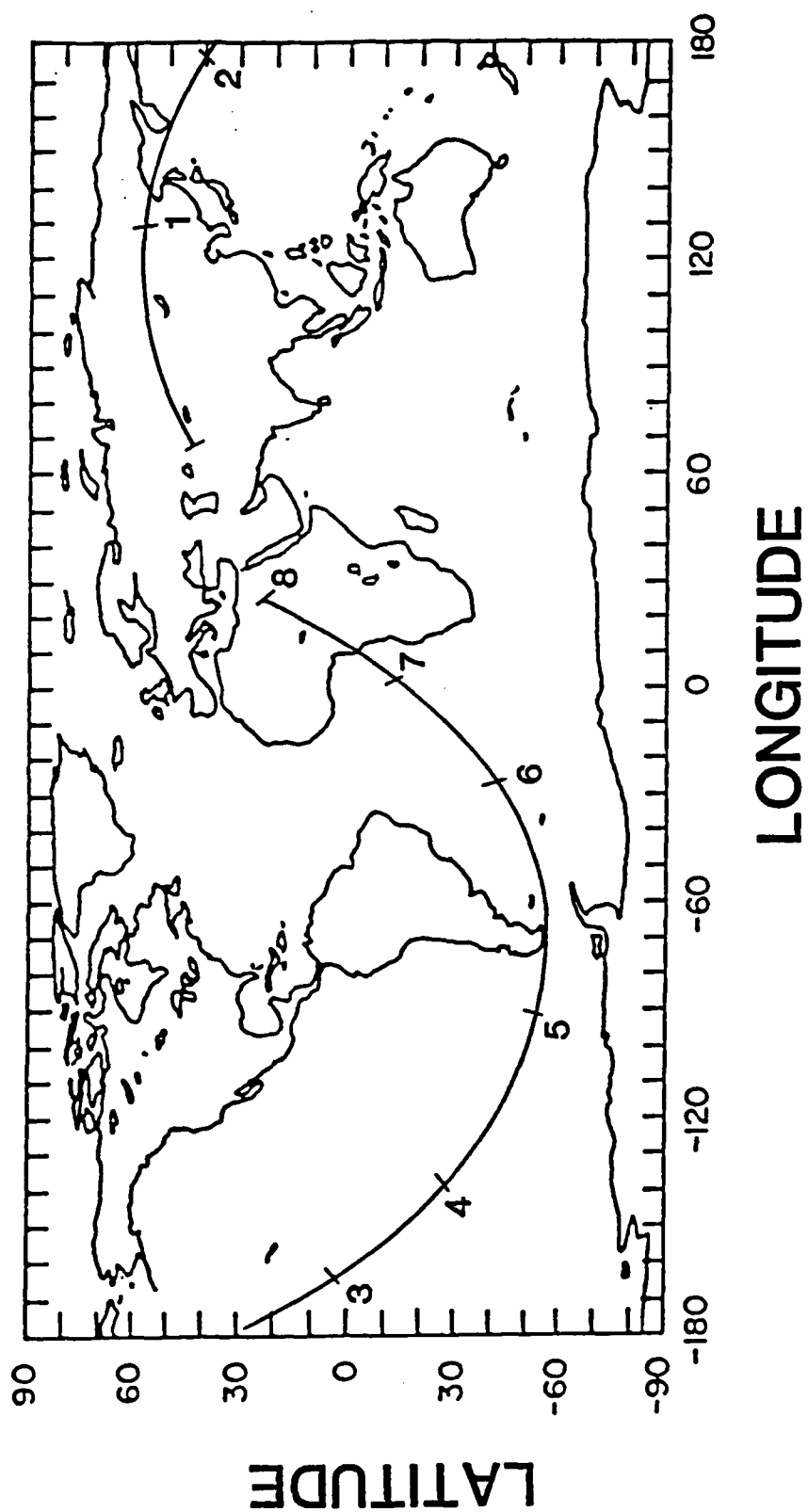


Figure 3. Ground track of the shuttle during data acquisition. Cycles are numbered where the NO 1-0 gamma band measurements were taken.

Table 1. Summary of relevant parameters for the spectral cycles

Cycle #	Geographic latitude	Geographic longitude	Solar zenith angle	Local time	Tangent ray height (km)
1	57°N	115°E	79.5°	11h56	105.7
2	37°N	175°E	84.8°	16h07	103.7
4	31°S	222°E	98.9°	19h36	106.0
5	56°S	269°E	100.8°	22h54	115.4
6	45°S	333°E	97.1°	3h22	111.6
7	12°S	3°E	89.8°	5h31	99.6
8	22°N	24°E	82.6°	7h07	95.4

one-dimensional profile centered at the tangent ray height. A software program, SPY, was developed by the Imaging Spectrometric Laboratory staff to separate the one-dimensional data into eight spatial lines, producing the spatial profiles. The three cycles viewing the lowest tangent altitudes, 8, 7, and 2, were chosen for analysis to gain a better understanding of nitric oxide in the mesosphere.

## RESULTS AND DISCUSSION

### Temperature

The rotational lines of the 1-0 gamma bands are temperature dependent and can be used to infer atmospheric temperature. Figure 4 shows the effect different rotational temperatures have on the rotational lines of the 1-0 band using a synthetic spectral model (Whiting et al., 1969). By inputting different temperatures, the synthetic spectrum was modeled to match the well defined rotational lines of the 1-0 band (Figure 5) to infer the rotational temperature of the band, and hence, the atmospheric temperature. This technique was used on cycles 2, 7, and 8, to obtain the temperature profiles shown in Figure 6. Each cycle clearly showed a bounded mesopause with the altitude of the mesopause varying with latitude.

### Intensity

The large altitude, hemisphere and latitudinal variations in the 1-0 NO gamma band are shown in Figure 7. Each 1-0 band is one dimensional and centered at the tangent ray height which is indicated in the figure. Cycle 2 clearly shows the larger amount of NO present in the sub-auroral region than at mid-latitudes (Rusch and Barth, 1975). The one-dimensional spectra for cycles 8, 7, and 2 in the 1850-2300 Å wavelength ranges are shown in Figure 8.

The ISO's capability to simultaneously obtain spatial as well as spectral data is clearly demonstrated in Figures 9 and 10. The figures show the 2 km spatial resolution of which the ISO is capable in the 1850-2300 Å wavelength range.

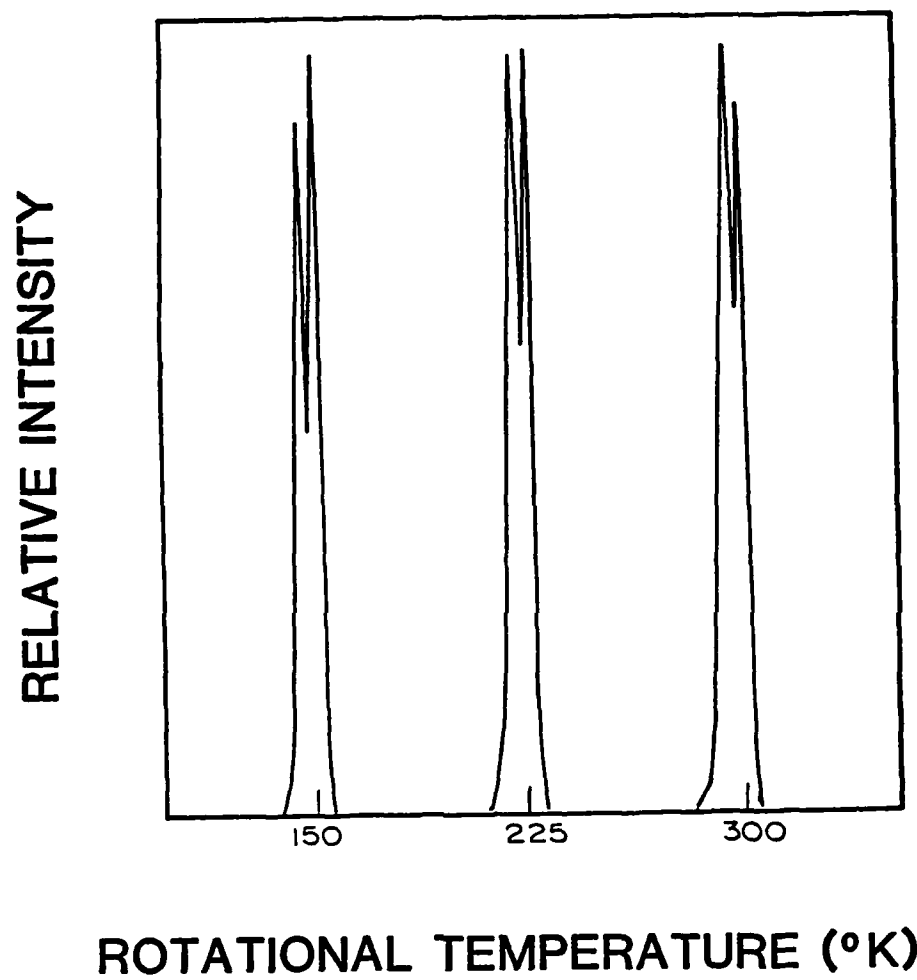


Figure 4. Effects of temperature on the rotational lines of the 1-0 NO gamma band.

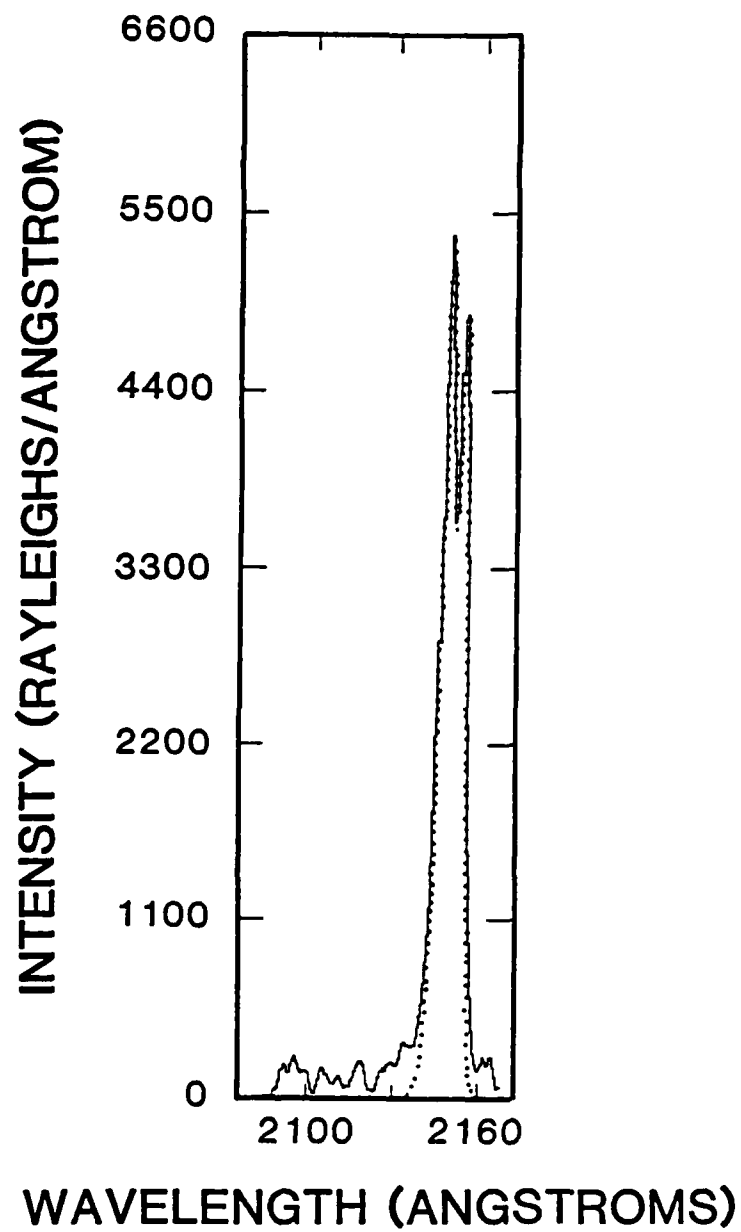


Figure 5. The synthetic spectrum model 1-0 gamma band (···) at a rotational temperature of 320K overlaid to match the data for atmospheric temperature inference.

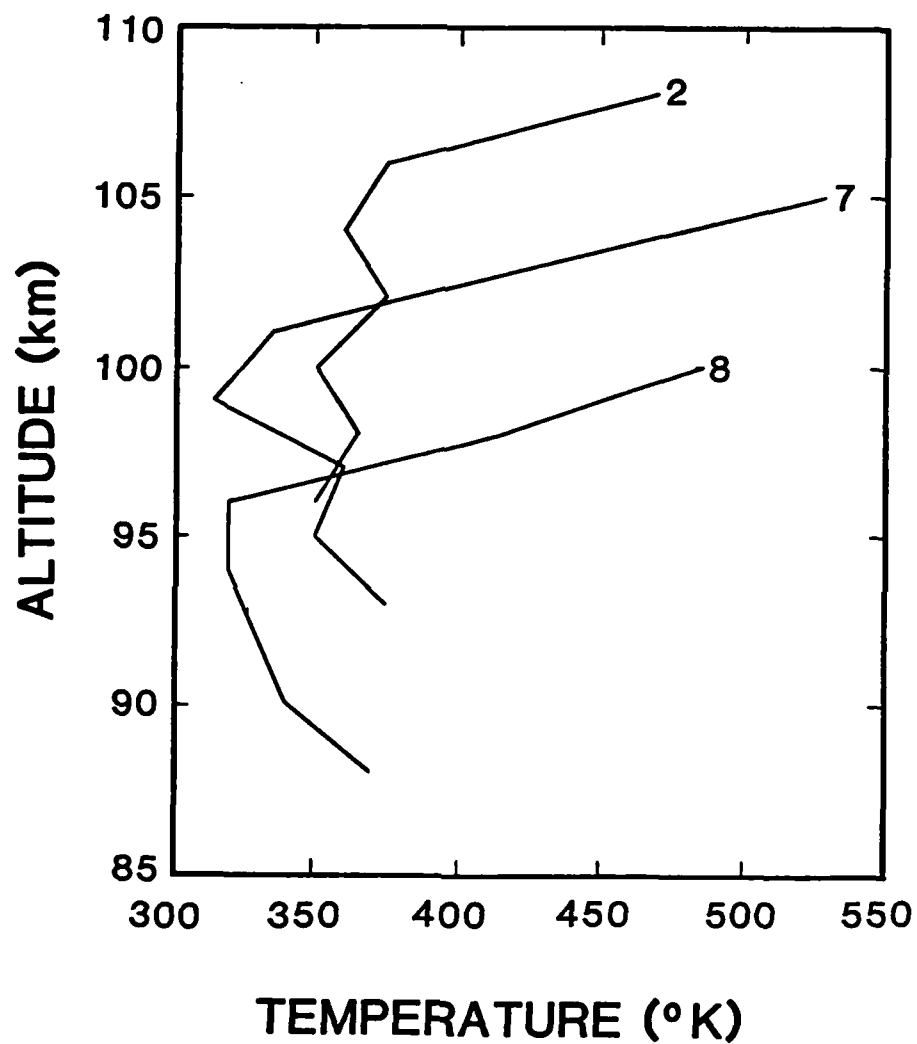


Figure 6. Inferred atmospheric temperature profiles for cycles 2, 7, and 8, as indicated.

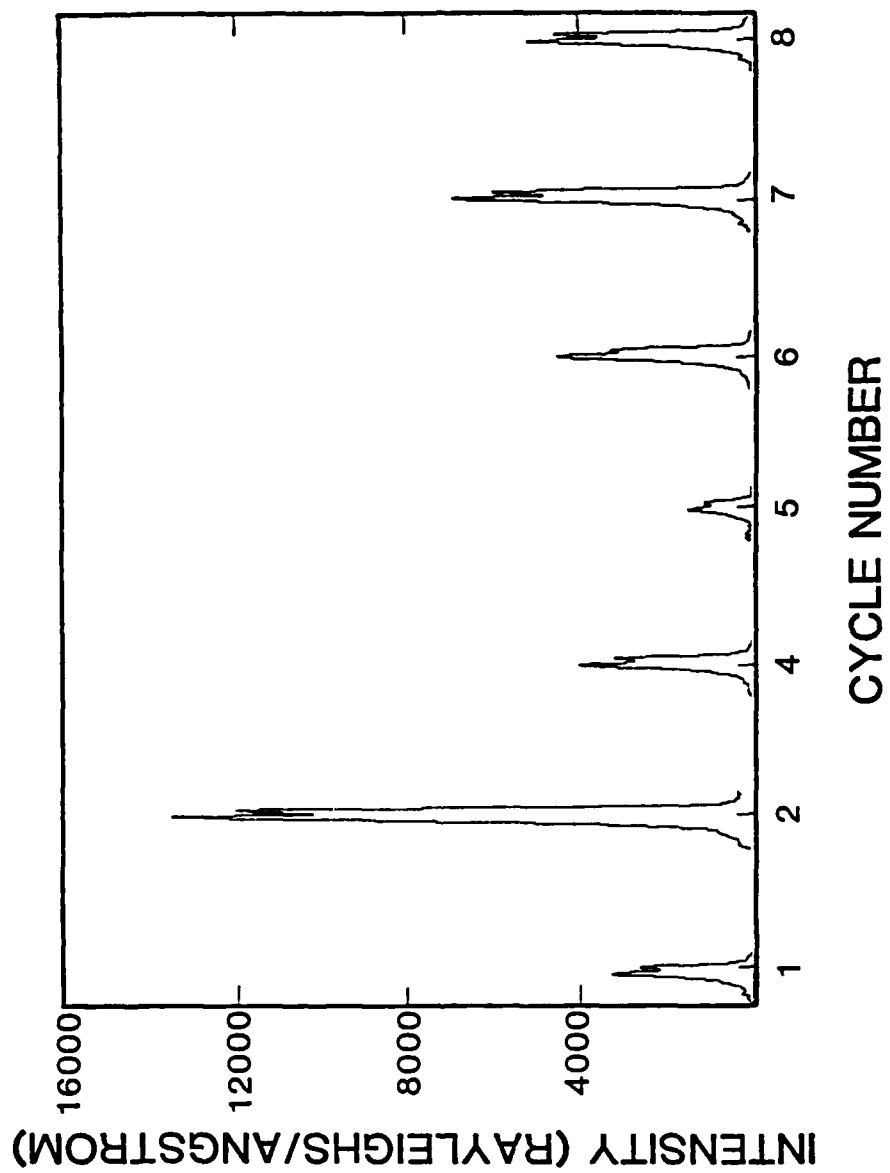


Figure 7. Latitudinal and seasonal variations of the one dimensional NO 1-0 gamma bands.

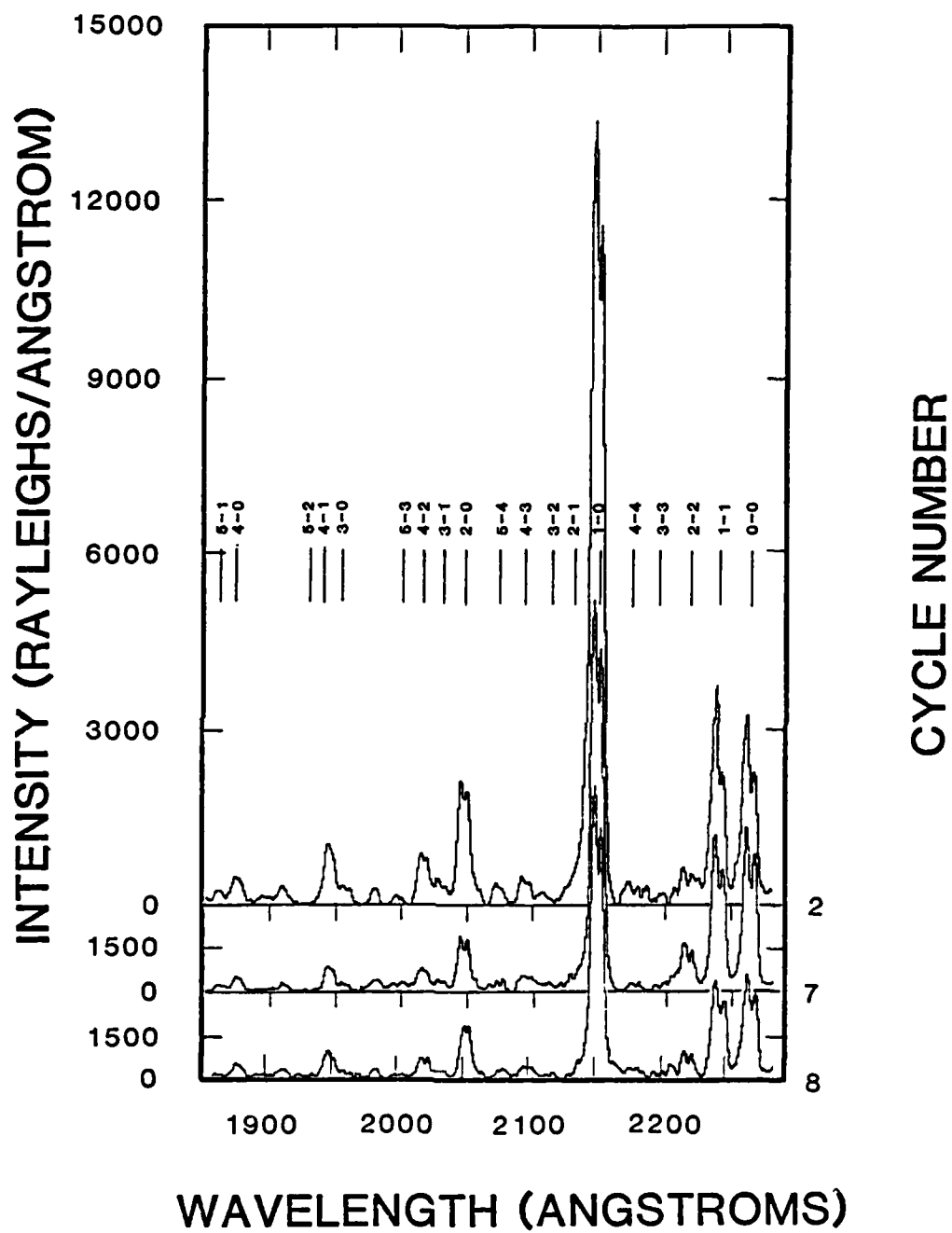


Figure 8. One dimensional spectra for the indicated cycles.

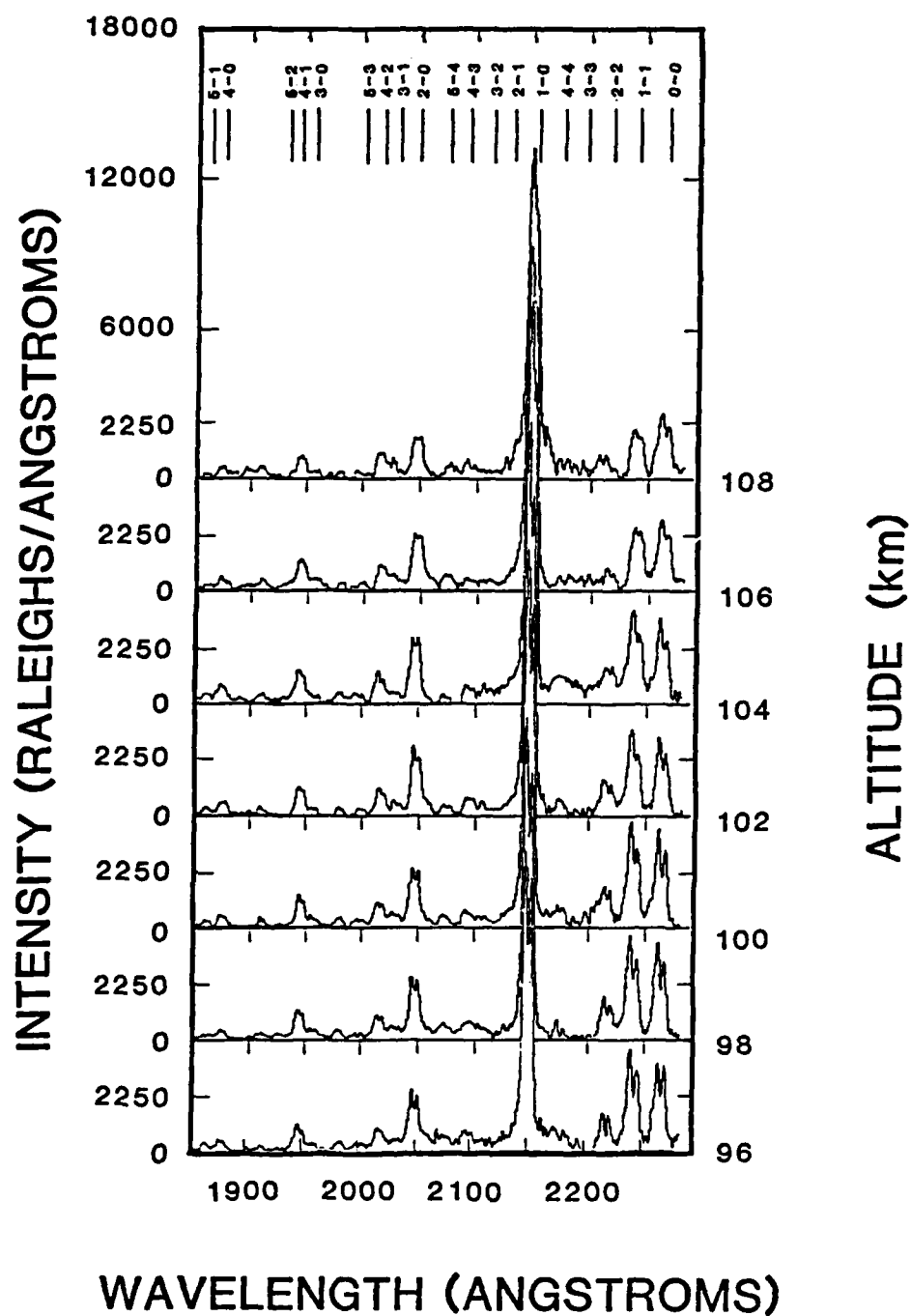


Figure 9. Spatial and spectral profiles of cycle 2.

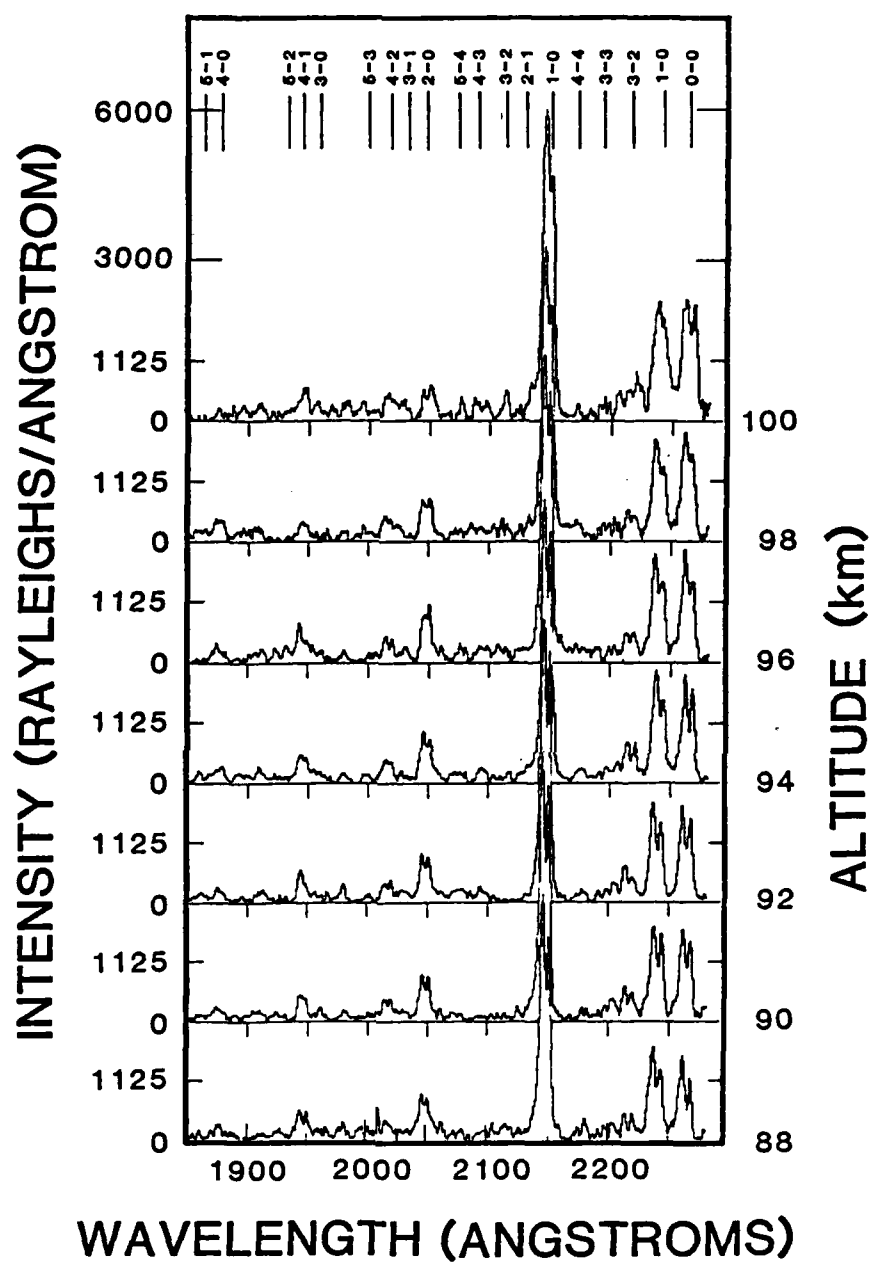


Figure 10. Spatial and spectral profiles of cycle 8.

Slant path intensity measurements for the 1-0 gamma band were obtained by integrating over the relevant wavelengths to produce the total intensity at each height. The spatial lines of the 1-0 band that were integrated are clearly shown in Figure 11, with their slant path intensity profiles shown in Figure 12.

The theoretical model used in this report was developed by Gérard et al. (1984). It is a two-dimensional model of  $N(^2D)$ ,  $N(^4S)$  and NO to investigate the global distribution of these species for December solstice conditions during solar cycle minimum. Figure 13 shows the calculated zonally averaged densities of NO for solar and particle-induced ionization during quiet and moderately disturbed auroral conditions (Gérard et al., 1984). Symmetry between the hemispheres was assumed, and the data for the southern hemisphere winter were used for the northern hemisphere winter.

The data obtained by the ISO were acquired for a slant path viewing geometry with tangent ray heights between 95-115 km, depending on the cycle. In order to compare the measured and theoretical intensities, the theoretical volume emission rate profiles were integrated along the correct geometrical path to obtain the slant path surface brightness. The g-factor,  $7.69E-6$  photons  $sec^{-1}$  (Barth, 1965), was used to calculate the volume emission rate. The corresponding theoretical profiles, quiet and disturbed, for each cycle's latitude were plotted along with the ISO's measured profile. Cycles 8, 7 and 2 are shown in Figures 14, 15, and 16, respectively.

The Kp index is a measure of the earth's geomagnetic activity. On December 7, 1983, the Kp total index for the day was 32 (Coffey, 1984), making it the fifth most disturbed day of the month. With

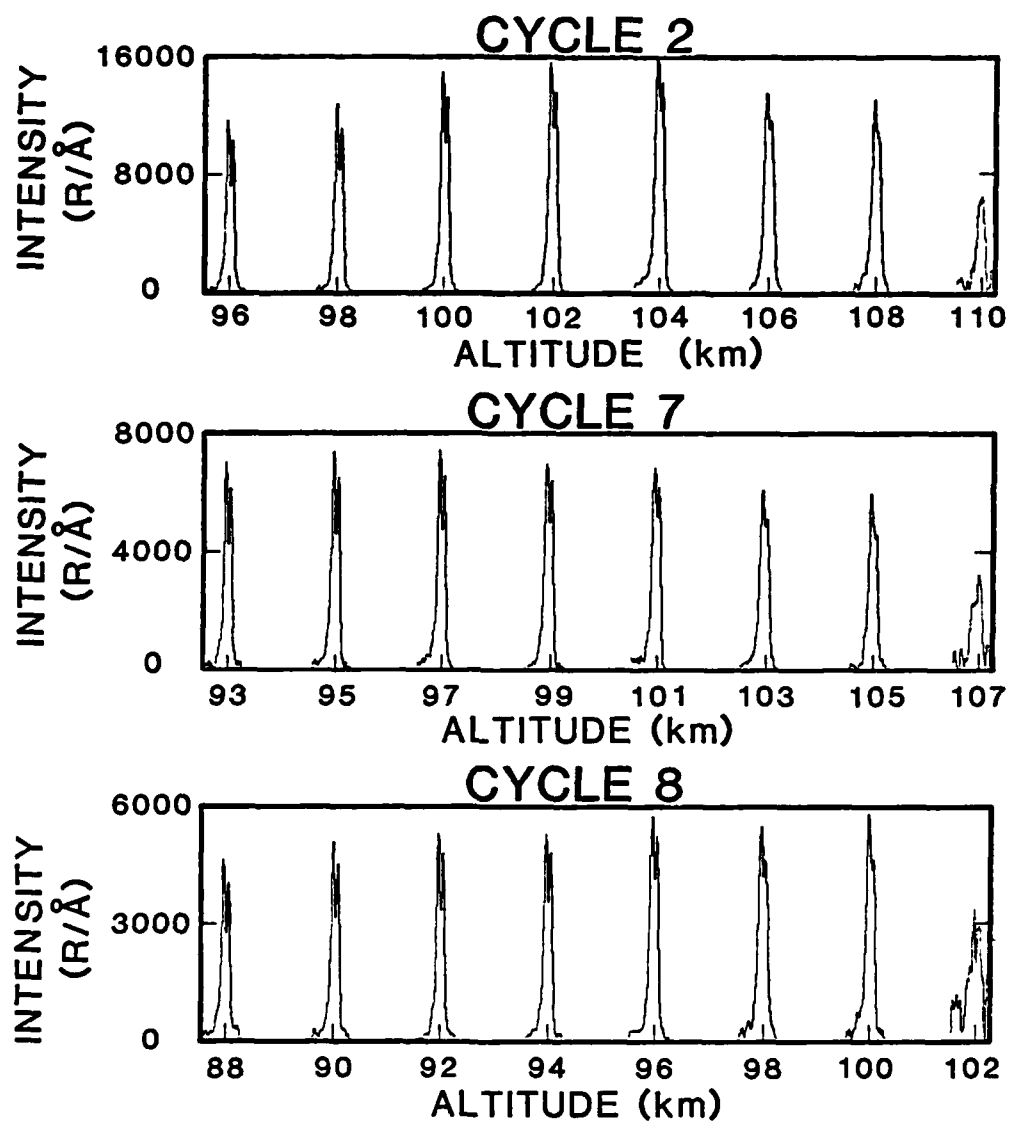
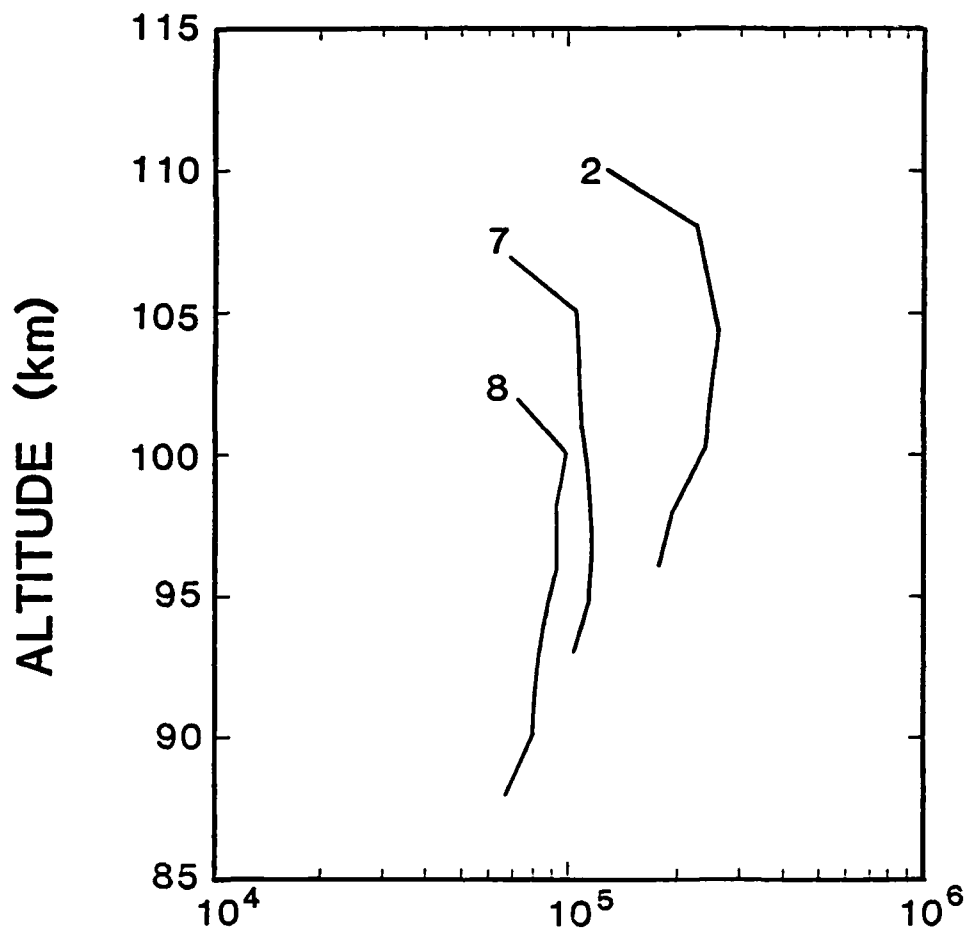


Figure 11. Spatially resolved 1-0 bands for the cycles indicated.



### SLANT PATH INTENSITY (RAYLEIGHS)

Figure 12. Slant path intensity profiles obtained from the spatially resolved 1-0 bands of cycles 2, 7, and 8, as indicated.

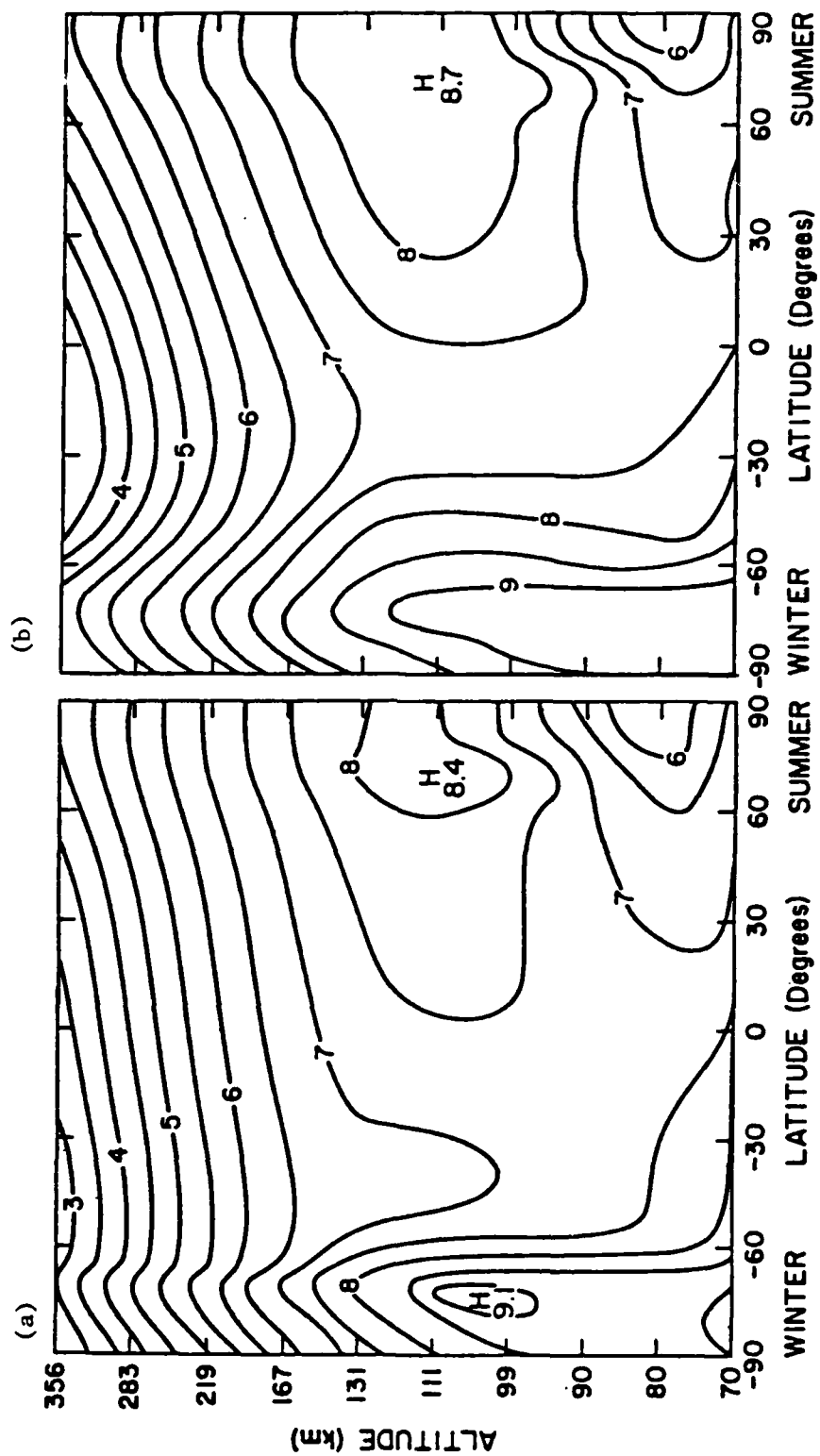


Figure 13. Contours of  $\log_{10}$  of zonally averaged densities of  $\text{NO}$  ( $\text{cm}^{-3}$ ) for solar and particle induced ionization (Gérard et al., 1984): (a) quiet conditions, (b) moderately disturbed conditions.

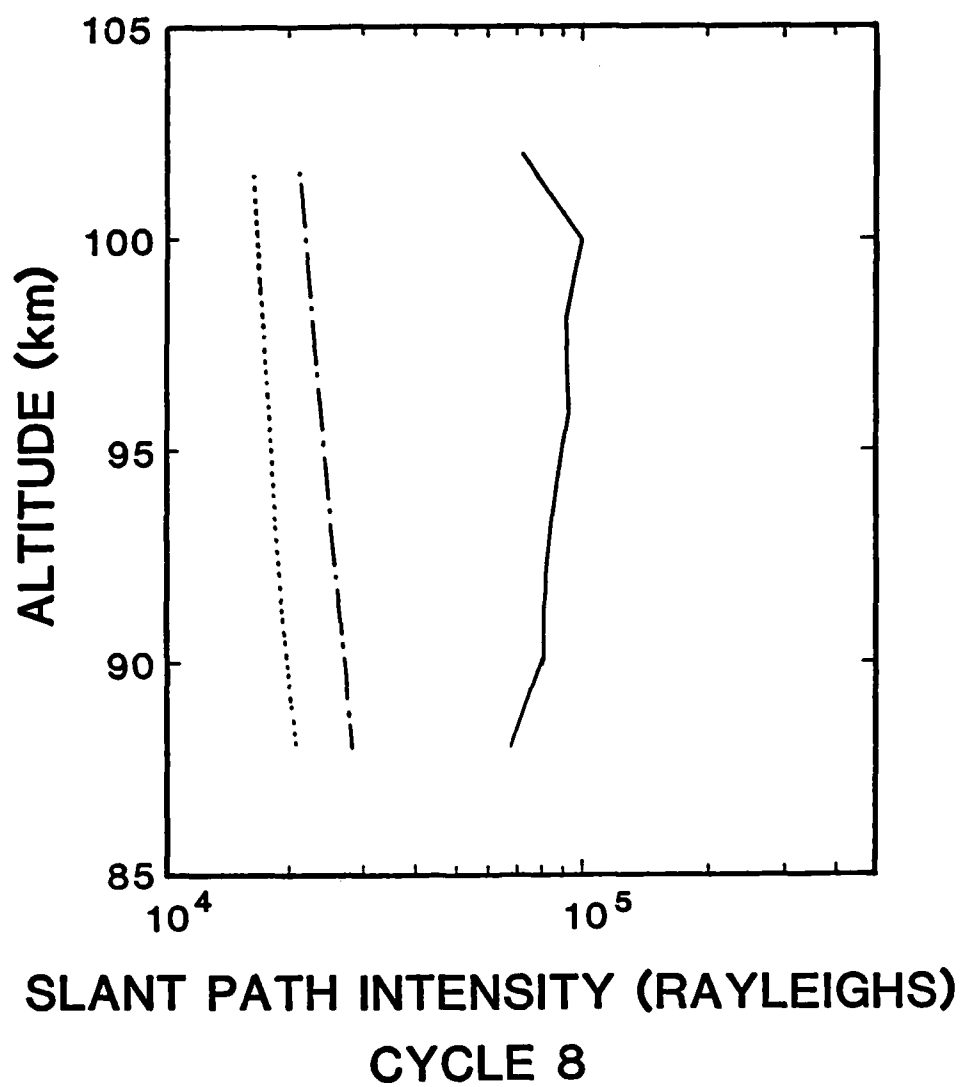


Figure 14. Slant path intensity profile for cycle 8 (—) compared with the quiet (···) and moderately disturbed (—·—) model conditions at 22°N latitude.

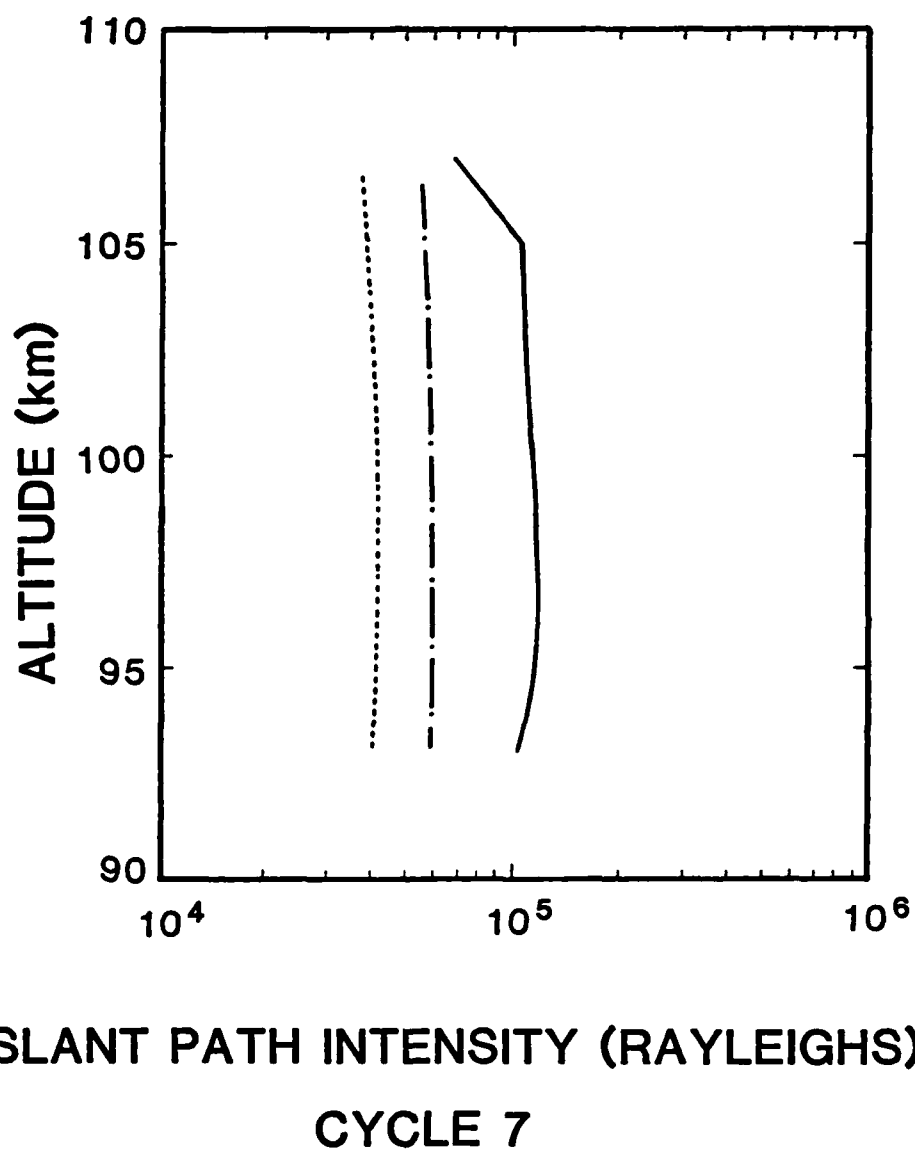


Figure 15. Slant path intensity profile for cycle 7 (—) compared with the quiet (···) and moderately disturbed (—·—) model conditions at 12°S latitude.

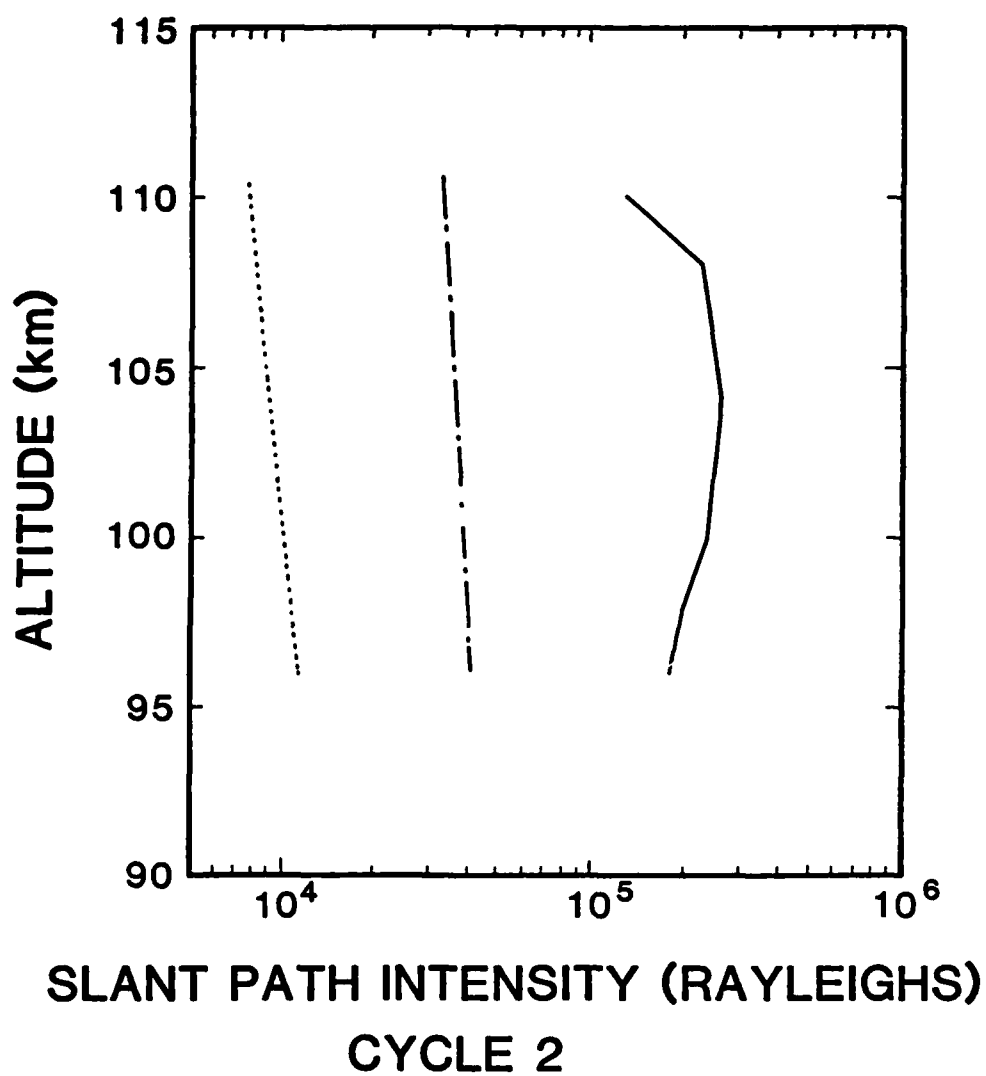


Figure 16. Slant path intensity profile for cycle 2 (—) compared with the quiet (...) and moderately disturbed (-.-.) model conditions at 37°N latitude.

this in mind, the best agreement between actual data and theory occurred in cycle 7 (Figure 15). Cycles 8 and 2 clearly suggest much more NO than theory. The largest deviation, a factor of 8, occurred at 100 km in cycle 8, using the disturbed theoretical profiles for each cycle.

The large disparity between the slant path theoretical profiles and the ISO data, especially cycle 8, indicate either the conversion to slant path intensity is incorrect, or there is more NO than theory predicts. A quick computational check of the conversion was accomplished using the following equation (M. Torr, personal communication):

$$I_{sp} = g [NO] H (2\pi R/H)^{1/2} \quad [5]$$

where  $I_{sp}$  is the slant path intensity,  $g$  is the  $g$ -factor,  $[NO]$  is the concentration of NO,  $H$  is the scale height (9 km), and  $R$  is the radius of the earth. Using 100 km data for cycle 8,  $[NO] = 1.35E07 \text{ cm}^{-3}$  (from Figure 13), one obtains get a calculated slant path intensity of  $6.24E03$  rayleighs. The computer program result from Figure 14 shows approximately  $1.08E04$  rayleighs, less than twice the value from equation [5], indicating the conversion to slant path is done correctly.

During the same Spacelab 1 mission, infrared spectra of the earth's limb were obtained in absorption using the rising or setting sun as a source. On December 1, measurements of NO ( $1915 \text{ cm}^{-1}$ ) were obtained from 20 to 100 km at 66.89S, 118.1W (Laurent et al., 1984). Previous NO profiles (Meira, 1971, Baker et al., 1977; Tohmatsu and Iwagami, 1975) showed a clear minimum ( $10^6$ - $10^7 \text{ cm}^{-1}$ ) at approximately

85 km while Laurent's profile showed a clear maximum near 90 km ( $10^8 \text{ cm}^{-3}$ ) (see Figure 17). The vertical infrared NO profile from Spacelab 1 is shown in Figure 18 along with the vertical theoretical concentrations of the model for the same latitude. The measured and theoretical values agreed quite well near 100 km. Theory predicted less than actual data below 90 km. The Kp total index for December 1 was 22+ (Coffey, 1984) which related to an average quiet day. The largest deviation was a factor of 75 using the quiet theoretical profile at 80 km.

Two different volume emission rate profiles were used from 100 to 250 km to convert the infrared data to slant path intensity. Gerard's quiet theoretical profile matched the infrared data at 100 km and was used for one slant path profile with a thermospheric code developed by the Imaging Spectrometric Laboratory staff used for the other. The slant path intensity profiles are shown in Figure 19 along with the 1-0 band profiles obtained from the ISO. The conversion of the vertical volume emission rate profiles to slant path intensity was very sensitive to the vertical volume emission rate profiles. Although the same vertical profile was used from 80-100 km, the thermospheric code showed less than the model in the slant path.

#### Spectral Analysis

The synthetic spectral model was used to model the ISO data from cycle 2 at 102 km. The relative intensities of each band head (0-0, 1-0, 2-0, 3-0, 4-0) were scaled to match the data, with relative intensities of the other bands computed by the model using their Franck-Condon factors. The Franck-Condon factor is the probability

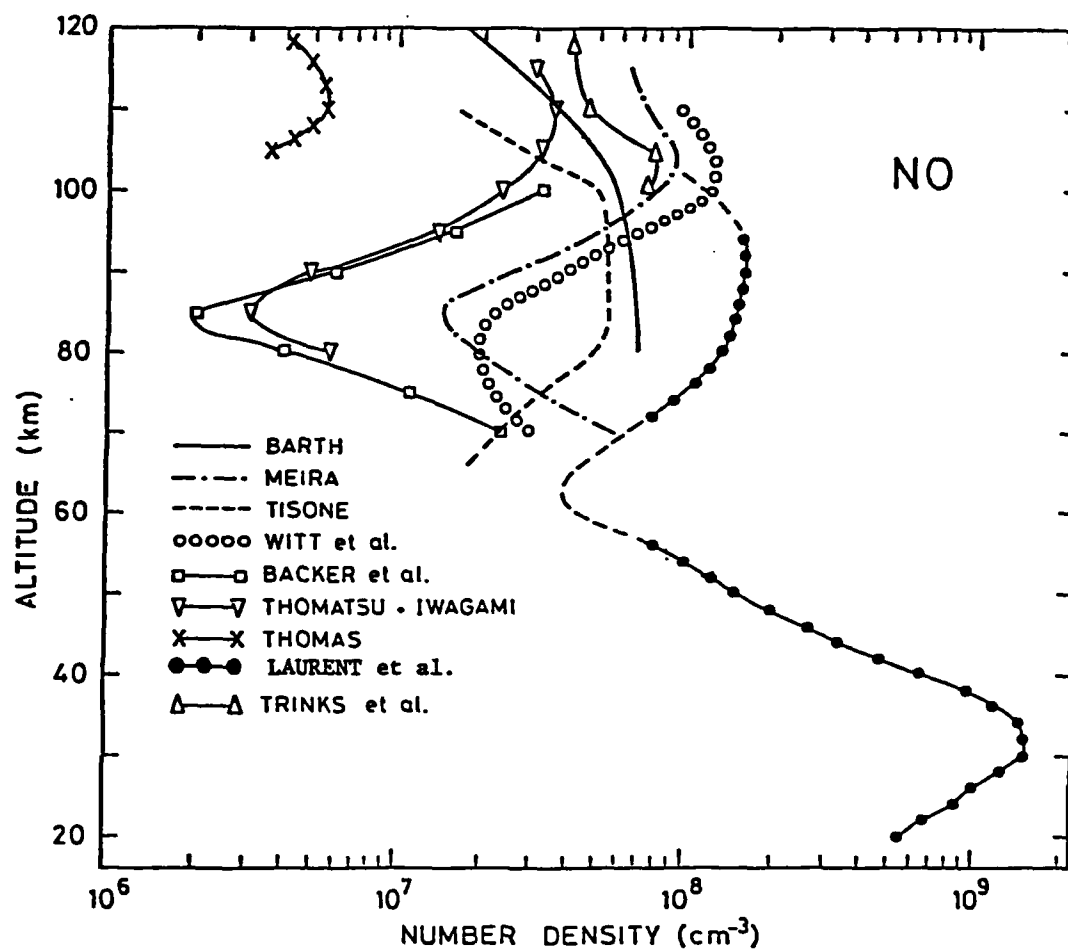


Figure 17. Nitric oxide densities obtained by Laurent et al., with results of other authors (Laurent et al., 1984).

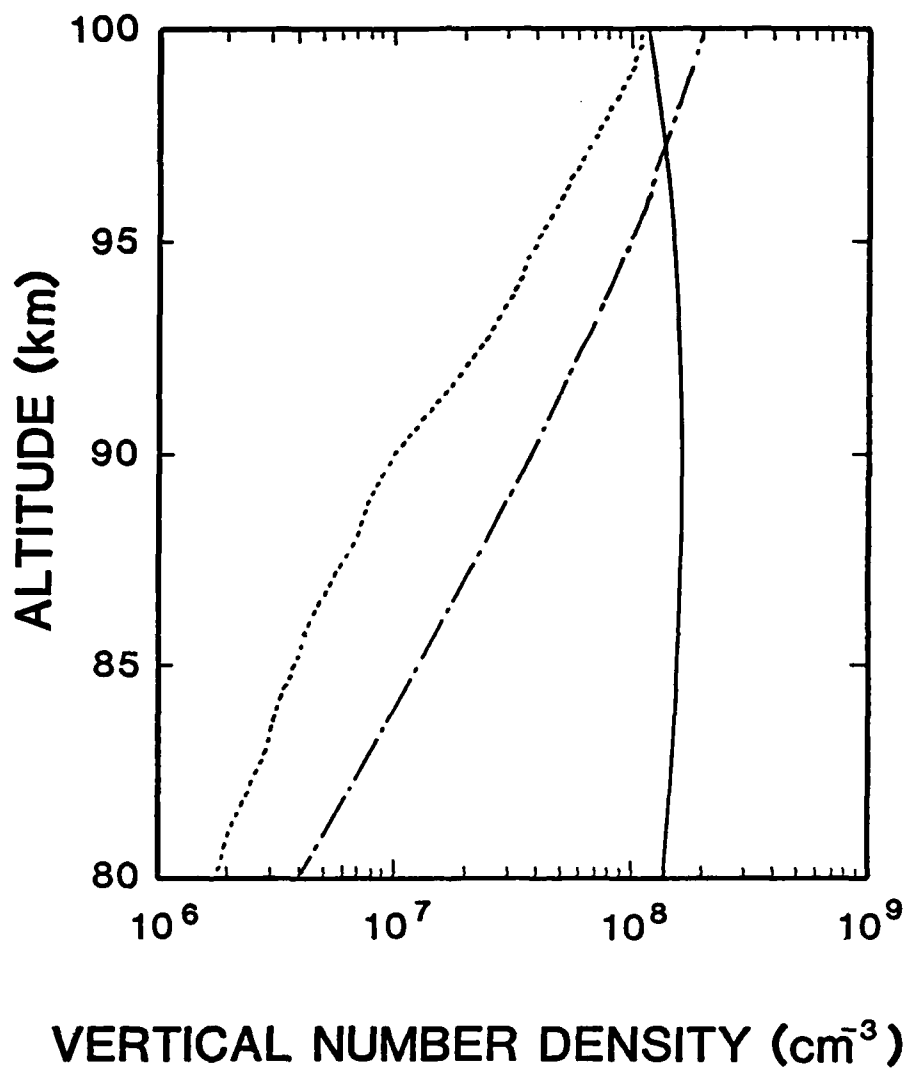


Figure 18. Vertical profile of NO concentration obtained in the infrared compared with the model's profiles at the same latitude, 68°S, for quiet (...) and disturbed (-.-.) conditions.

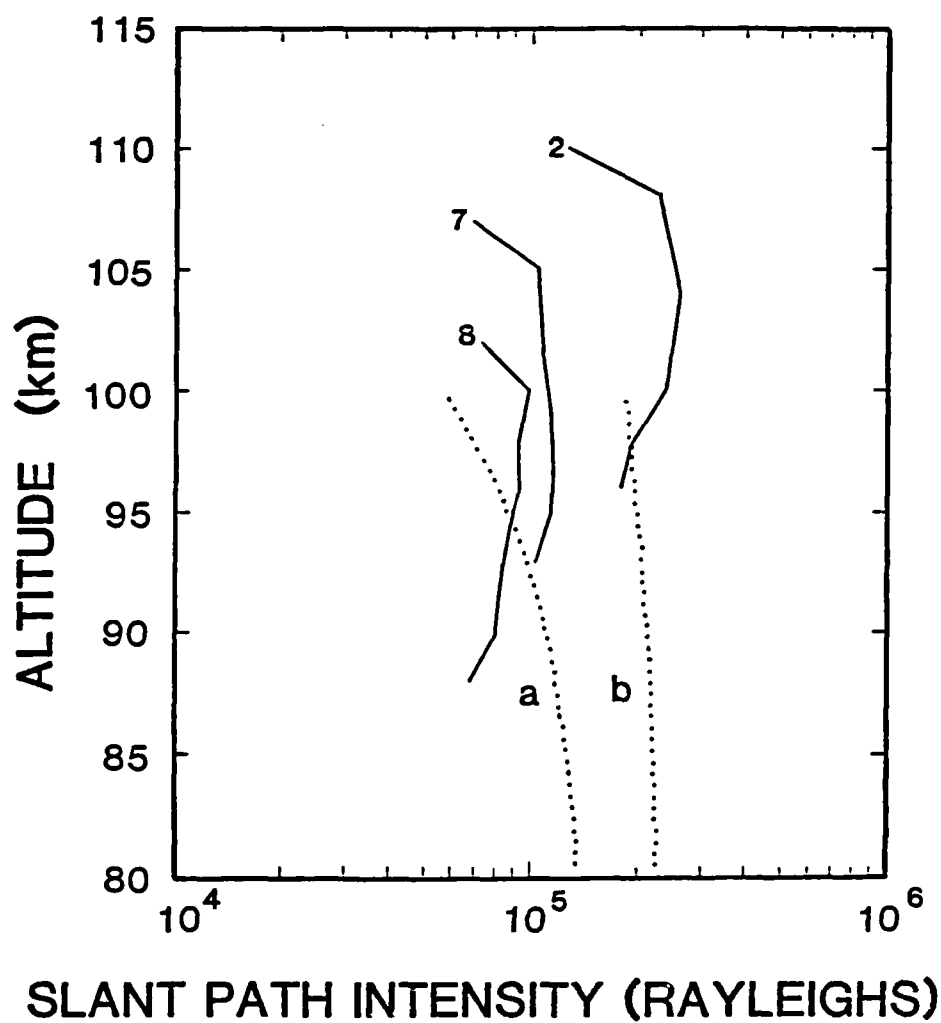


Figure 19. Slant path intensity profiles of the infrared data (...) using different volume emission rates above 100 km: (a) thermospheric code, (b) Gérard's quiet theoretical model. The intensity profiles for the indicated cycles (—) are also shown.

of a molecule radiating to a specific upper level. Figure 20a shows the ISO data, with Figure 20b showing the synthetic spectrum. The two spectra are in good agreement except for the 4-0 and 1-1 bands. There is an underlying 2-2 NO delta band accounting for the higher ISO intensity for the 4-0 band. The synthetic spectrum showed approximately half the relative intensity of the ISO's 1-1 band, indicating a problem with the 1-0 band.

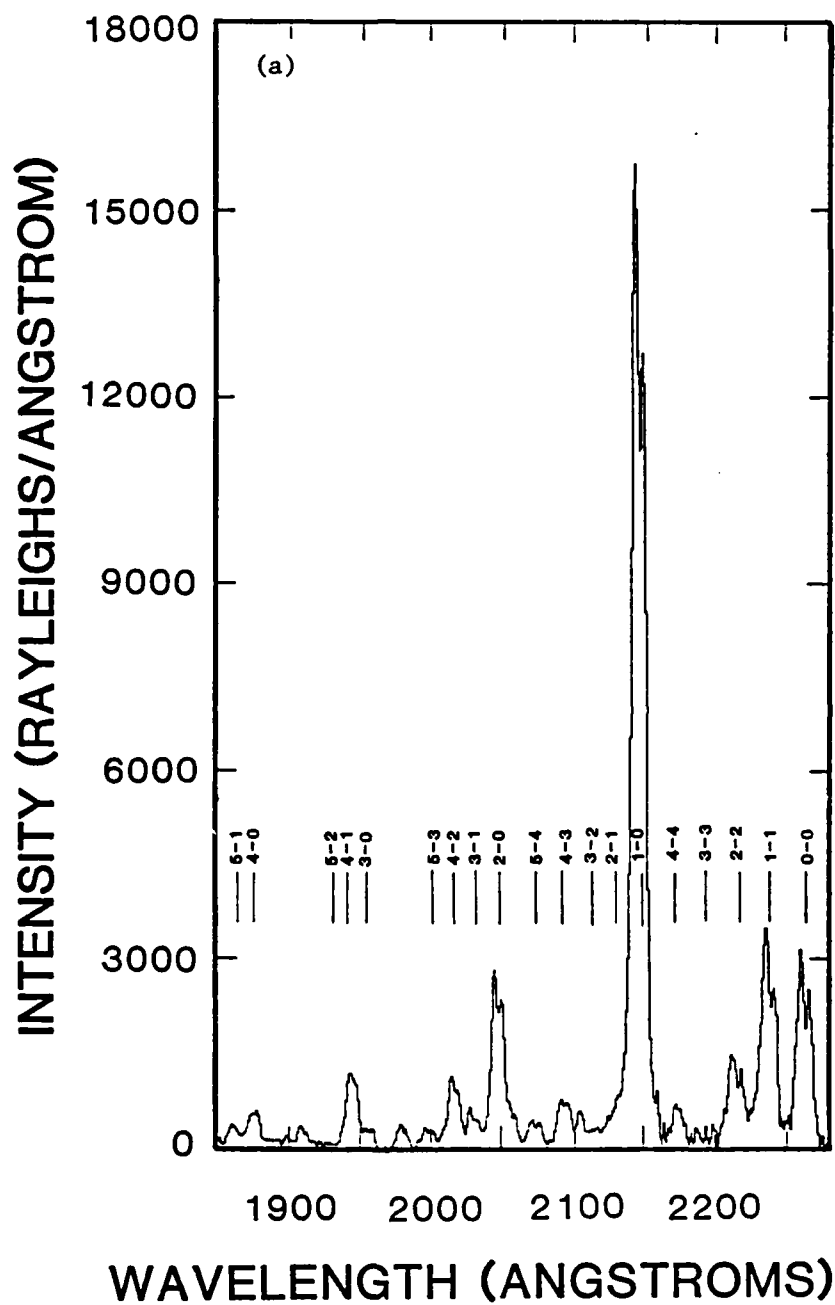


Figure 20. NO bands from cycle 2 at 102 km in altitude (a) with the synthetic spectrum (b) for the same wavelength range overlaid.

## CONCLUSIONS

The temperature profiles (Figure 6) obtained from the ISO data were warmer than the standard atmospheric profile (see Figure 1) but consistent with their latitude and altitude. Cycles 7 and 8 showed a gradual decrease in temperature before the rapid increase at the mesopause was reached. Cycle 2 showed a fairly isothermal layer below the mesopause.

The vertical profile obtained in the infrared showed a much higher concentration of NO in the mesosphere than previously reported. The same results were anticipated here, but the differences in latitude, altitude, and the sensitivity of converting data to slant path intensities made it difficult to make an objective statement. Both sets of data showed higher slant path intensity profiles than the most recent theoretical model predicted for their respective latitudes.

The synthetic spectrum matched the ISO data quite well with the exception of the 1-1 band. For the model to match the intensity of the 1-1 band, the relative intensity of the 1-0 band would have to increase by approximately one-third. If this is the case, the ISO did not see all the NO 1-0 band in the atmosphere. One possible reason for the lesser intensity of the 1-0 band could be the absorption of the 1-0 band in the atmosphere. This could account for the fact the infrared data obtained from Spacelab 1 showed higher concentrations of NO in the mesosphere than previously reported. Study of this possibility is suggested for further research.

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